CSE 241 Lecture 5

Adopted from the lecture slides of the book:
Absolute C++ by Walter Savitch, Kenrick Mock

Learning Objectives

- Introduction to Arrays
  - Declaring and referencing arrays
  - For-loops and arrays
  - Arrays in memory
- Arrays in Functions
  - Arrays as function arguments, return values
- Programming with Arrays
  - Partially Filled Arrays, searching, sorting
- Multidimensional Arrays

Introduction to Arrays

- Array definition:
  - A collection of data of same type
- First "aggregate" data type
  - Means "grouping"
  - `int`, `float`, `double`, `char` are simple data types
- Used for lists of like items
  - Test scores, temperatures, names, etc.
  - Avoids declaring multiple simple variables
  - Can manipulate "list" as one entity

Declaring Arrays

- Declare the array → allocates memory
  `int score[5];`
  - Declares array of 5 integers named "`score`"
  - Similar to declaring five variables:
    `int score[0], score[1], score[2], score[3], score[4]`
- Individual parts called many things:
  - Indexed or subscripted variables
  - "Elements" of the array
  - Value in brackets called index or subscript
    - Numbered from `0` to `size -1`

Accessing Arrays

- Access using index/subscript
  - `cout << score[3];`
- Note two uses of brackets:
  - In declaration, specifies SIZE of array
  - Anywhere else, specifies a subscript
- Size, subscript need not be literal
  - `int score[MAX_SCORES];`
  - `score[n+1] = 99;`
    - If `n` is 2, identical to: `score[3]`

Array Usage

- Powerful storage mechanism
- Can issue command like:
  - "Do this to i^{th} indexed variable" where i is computed by program
  - "Display all elements of array score"
  - "Fill elements of array score from user input"
  - "Find highest value in array score"
  - "Find lowest value in array score"

Array Program Example:

```
1 //Reads in five scores and shows how much each
2 //score differs from the highest score.
3 #include <iostream>
4 using namespace std;
5 int main( )
6 {
7   int i, score[5], max;
8   cout << "Enter 5 scores:\n";
9   cin >> score[0];
10  max = score[0];
11  for (i = 1; i < 5; i++)
12  {
13      cin >> score[i];
14      if (score[i] > max)
15      max = score[i];
16      //max is the largest of the values score[0],..., score[i] .
17  }
18  cout << "The highest score is " << max << endl
19       << "The scores and their\n"
20       << "differences from the highest are:\n";
21  for (i = 0; i < 5; i++)
22       cout << score[i] << " off by "
23            << (max - score[i]) << endl;
24  return 0;
25 }
```

`for`-loops with Arrays

- Natural counting loop
  - Naturally works well "counting through" elements of an array
- Example:

```
for (idx = 0; idx<5; idx++)
{
    cout << score[idx] << "off by "
         << max - score[idx] << endl;
}
```

  - Loop control variable (`idx`) counts from `0 - 5`

Major Array Pitfall

- Array indexes always start with zero!
- Zero is “first” number to computer scientists
- C++ will “let” you go beyond range
  - Unpredictable results
  - Compiler will not detect these errors!
- Up to programmer to “stay in range”

Major Array Pitfall Example

- Indexes range from `0` to (`array_size - 1`)
  - Example:
    ```
    double temperature[24]; // 24 is array size
    // Declares array of 24 double values called temperature
    ```
    - They are indexed as:
      `temperature[0], temperature[1] … temperature[23]`
  - Common mistake:
    `temperature[24] = 5;`
    - Index `24` is “out of range”!
    - No warning, possibly disastrous results

Defined Constant as Array Size

- Always use defined/named constant for array size
- Example:
```
const int NUMBER_OF_STUDENTS = 5;
int score[NUMBER_OF_STUDENTS];
```
- Improves readability
- Improves versatility
- Improves maintainability

Uses of Defined Constant

- Use everywhere size of array is needed
  - In `for`-loop for traversal:

```
for (idx = 0; idx < NUMBER_OF_STUDENTS; idx++)
{
     // Manipulate array
}
```

  - In calculations involving size:

```
lastIndex = (NUMBER_OF_STUDENTS - 1);
```

  - When passing array to functions (later)
- If size changes → requires only ONE change in program!

Ranged-Based For Loop

- The C++11 ranged-based for loop makes it easy to iterate over each element in a loop
- Format

```
for (datatype varname : array)
{
    //  varname is set to each successive
    //  element in the array
}
```

- Example

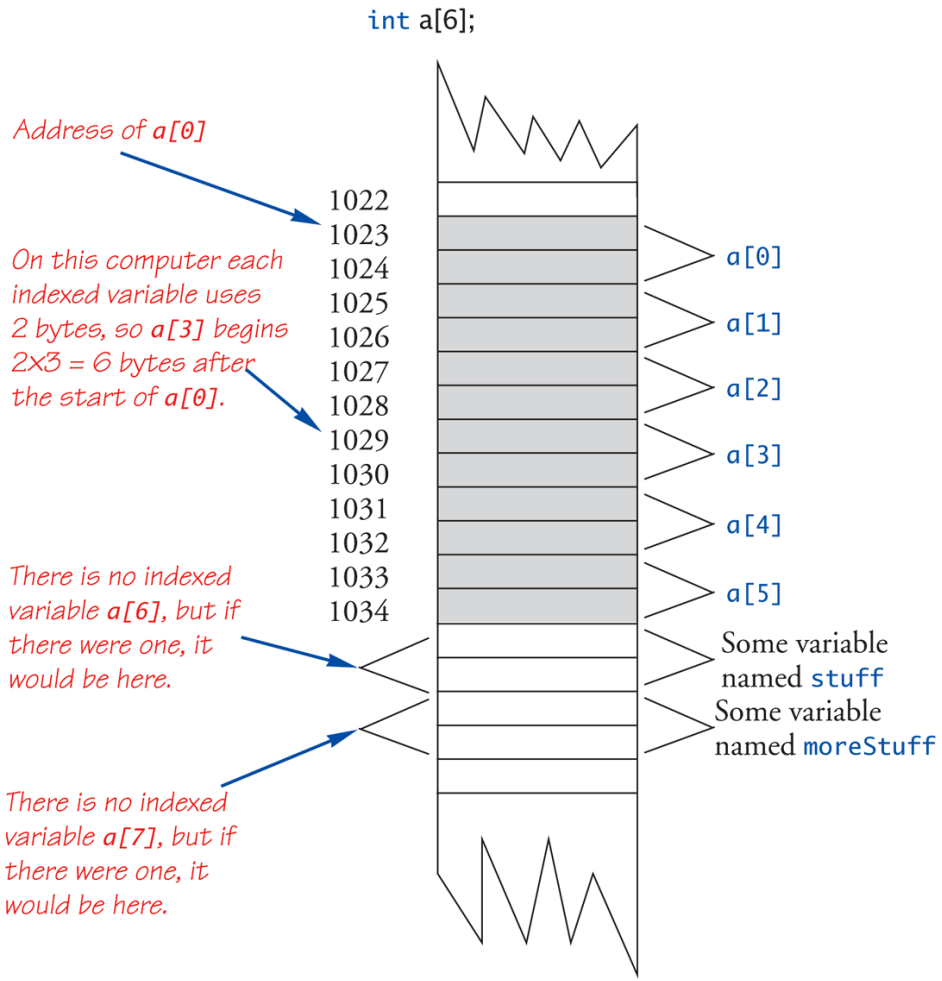
```
int arr[] = {20, 30, 40, 50};
for (int x : arr)
    cout << x << " ";
cout << endl;
```

Arrays in Memory

- Recall simple variables:
  - Allocated memory in an “address”
- Array declarations allocate memory for entire array
- Sequentially-allocated
  - Means addresses allocated “back-to-back”
  - Allows indexing calculations
    - Simple “addition” from array beginning (index 0)

An Array in Memory

Display 5.2 **An Array in Memory**



Initializing Arrays

- As simple variables can be initialized at declaration:
  ```
  int price = 0;     // 0 is initial value
  ```
- Arrays can as well:
  ```
  int children[3] = {2, 12, 1};
  ```
  - Equivalent to following:
    ```
    int children[3];
    children[0] = 2;
    children[1] = 12;
    children[2] = 1;
    ```

Auto-Initializing Arrays

- If fewer values than size supplied:
  - Fills from beginning
  - Fills "rest" with zero of array base type
- If array-size is left out
  - Declares array with size required based on number of initialization values
  - Example:
    ```
    int b[] = {5, 12, 11};
    ```
    - Allocates array `b` to size `3`

Arrays in Functions

- As arguments to functions
  - Indexed variables
    - An individual “element” of an array can be function parameter
  - Entire arrays
    - All array elements can be passed as “one entity”
- As return value from function
  - Can be done → chapter 10

Indexed Variables as Arguments

- Indexed variable handled same as simple variable of array base type
- Given this function declaration:
```
void myFunction(double par1);
```
- And these declarations:
```
int i;  double n, a[10];
```
- Can make these function calls:
```
myFunction(i);     // i is converted to double
myFunction(a[3]); // a[3] is double
myFunction(n);     // n is double
```

Subtlety of Indexing

- Consider:
  `myFunction(a[i]);`
  - Value of `i` is determined first
    - It determines which indexed variable is sent
  - `myFunction(a[i*5]);`
  - Perfectly legal, from compiler's view
  - Programmer responsible for staying "in-bounds" of array

Entire Arrays as Arguments

- Formal parameter can be entire array
  - Argument then passed in function call is array name
  - Called “array parameter”
- Send size of array as well
  - Typically done as second parameter
  - Simple int type formal parameter

Entire Array as Argument Example

- Given previous example:
- In some `main()` function definition, consider this calls:

```
int score[5], numberOfScores = 5;
fillup(score, numberOfScores);
```

  - 1st argument is entire array
  - 2nd argument is integer value
- Note no brackets in array argument!

Array as Argument: How?

- What's really passed?
- Think of array as 3 "pieces"
  - Address of first indexed variable (`arrName[0]`)
  - Array base type
  - Size of array
- Only 1st piece is passed!
  - Just the beginning address of array
  - Very similar to "pass-by-reference"

Array Parameters

- May seem strange
  - No brackets in array argument
  - Must send size separately
- One nice property:
  - Can use SAME function to fill any size array!
  - Exemplifies "re-use" properties of functions
  - Example:

```
int score[5], time[10];
fillUp(score, 5);
fillUp(time, 10);
```

The const Parameter Modifier

- Recall: array parameter actually passes address of 1st element
  - Similar to pass-by-reference
- Function can then modify array!
  - Often desirable, sometimes not!
- Protect array contents from modification
  - Use "`const`" modifier before array parameter
    - Called "constant array parameter"
    - Tells compiler to "not allow" modifications

Functions that Return an Array

- Functions cannot return arrays same way simple types are returned
- Requires use of a “pointer”
- Will be discussed in chapter 10...

Programming with Arrays

- Plenty of uses
  - Partially-filled arrays
    - Must be declared some “max size”
  - Sorting
  - Searching

Partially-filled Arrays

- Difficult to know exact array size needed
- Must declare to be largest possible size
  - Must then keep "track" of valid data in array
  - Additional "tracking" variable needed
    - `int numberUsed;`
    - Tracks current number of elements in array

Partially-filled Arrays Example:

```
1 //Shows the difference between and
// each of a list of golf scores their average .
2 #include <iostream>
3 using namespace std;
4 const int MAX_NUMBER_SCORES = 10;
5 void fillArray( int a[], int size, int& numberUsed);
6 //Precondition: size is the declared size of the array a .
7 //Postcondition: numberUsed is the number of values stored in a
8 //a[0] through a[numberUsed-1] have been filled with
9 //nonnegative integers read from the keyboard .
10 double computeAverage( const int a[], int numberUsed);
11 //Precondition: a[0] through a[numberUsed-1] have values;
//numberUsed > 0.
12 //Returns the average of numbers a[0] through a[numberUsed-1]
13 void showDifference( const int a[], int numberUsed);
14 //Precondition: The first numberUsed indexed variables of a
have values .
15 //Postcondition: Gives screen output showing how much each of
the first
16 //numberUsed elements of the array a differs from their
average.
```

```
17 int main( )
18 {
19  int score[MAX_NUMBER_SCORES], numberUsed;
20  cout << "This program reads golf scores and shows\n"
21       << "how much each differs from the average.\n";
22  cout << "Enter golf scores:\n";
23  fillArray(score, MAX_NUMBER_SCORES, numberUsed);
24  showDifference(score, numberUsed);
25 return 0;
26 }
```

```
27 void fillArray( int a[], int size, int &
numberUsed)
28 {
29  cout << "Enter up to " << size << "
nonnegative whole numbers.\n"
30       << "Mark the end of the list with a
negative number.\n";
31  int next, index = 0;
32  cin >> next;
33  while ((next >= 0) && (index < size))
34  {
35      a[index] = next;
36      index++;
37      cin >> next;
38  }
39  numberUsed = index;
40 }
```

```
41 double computeAverage( const int a[], int numberUsed)
42 {
43  double total = 0;
44  for (int index = 0; index < numberUsed; index++)
45      total = total + a[index];
46  if (numberUsed > 0)
47  {
48      return (total/numberUsed);
49  }
50  else
51  {
52      cout << "ERROR: number of elements is 0 in
computeAverage.\n"
53           << "computeAverage returns 0.\n";
54      return 0;
55  }
56 }
57 void showDifference( const int a[], int numberUsed)
58 {
59  double average = computeAverage(a, numberUsed);
60  cout << "Average of the " << numberUsed
61      << " scores = " << average << endl
62      << "The scores are:\n";
63  for ( int index = 0; index < numberUsed; index++)
64      cout << a[index] << " differs from average by "
65           << (a[index] - average) << endl;
66 }
```

Global Constants vs. Parameters

- Constants typically made “global”
  - Declared above `main()`
- Functions then have scope to array size constant
  - No need to send as parameter then?
    - Technically yes
  - Why should we anyway?
    - Function definition might be in separate file
    - Function might be used by other programs!

Searching an Array

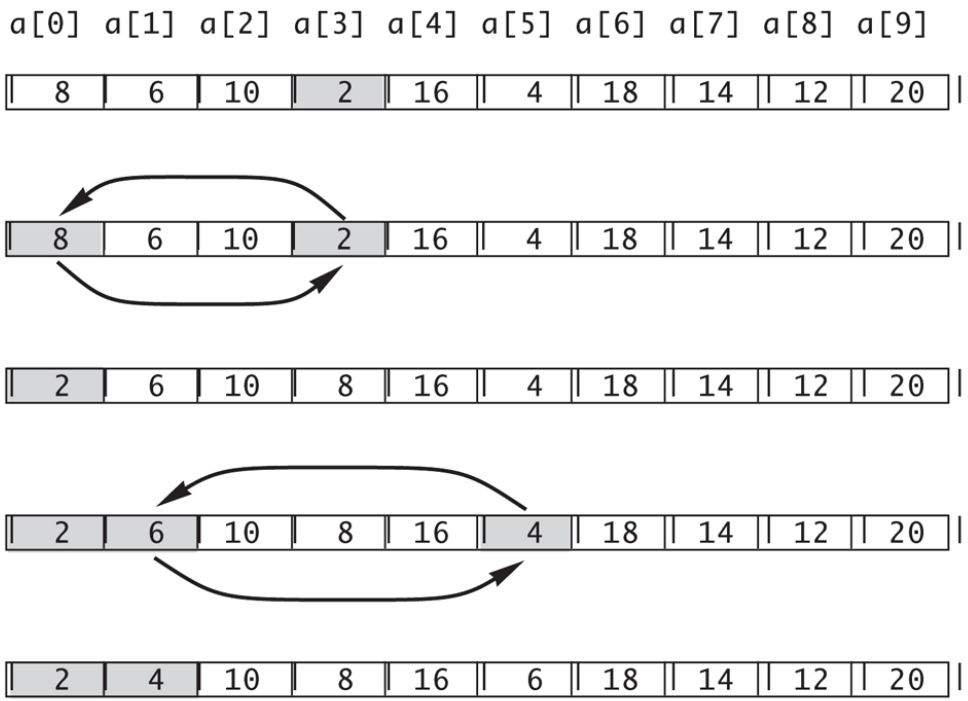
```
1 //Searches a partially filled array of nonnegative
integers .
2 #include <iostream>
3 using namespace std;
4 const int DECLARED_SIZE = 20;
5 void fillArray( int a[], int size, int & numberUsed);
6 //Precondition: size is the declared size of the array a
7 //Postcondition: numberUsed is the number of values
stored in a .
8 //a[0] through a[numberUsed-1] have been filled with
9 //nonnegative integers read from the keyboard .
10 int search( const int a[], int numberUsed, int target);
11 //Precondition: numberUsed is <= the declared size of a.
12 //Also, a[0] through a[numberUsed -1] have values .
13 //Returns the first index such that a[index] == target ,

40 int search( const int a[], int numberUsed, int target)
41 {
42  int index = 0;
43  bool found = false ;
44  while ((!found) && (index < numberUsed))
45      if (target == a[index])
46          found = true ;
47      else
48          index++;
49  if (found)
50      return index;
51  else
52      return -1;
53 }
```

```
15 int main( )
16 {
17  int arr[DECLARED_SIZE], listSize, target;
18  fillArray(arr, DECLARED_SIZE, listSize);
19  char ans;
20  int result;
21  do
22  {
23      cout << "Enter a number to search for: ";
24      cin >> target;
25      result = search(arr, listSize, target);
26      if (result == -1)
27          cout << target << " is not on the list.\n";
28      else
29          cout << target << " is stored in array position "
30              << result << endl
31              << "(Remember: The first position is 0.)\n";
32          cout << "Search again?(y/n followed by Return): ";
33          cin << ans;
34  } while ((ans != 'n') && (ans != 'N'));
35  cout << "End of program.\n";
36  return 0;
37 }
```

Sorting an Array:

- Selection Sort Algorithm

Display 5.7 Selection Sort



Sorting an Array Example:

```
1 //Tests the procedure sort .
2 #include <iostream>
3 using namespace std;

9 void sort( int a[], int numberUsed);
10 //Precondition: numberUsed <= declared size of the array a
11 //The array elements a[0] through a[numberUsed - 1] have
values .
12 //Postcondition: The values of a[0] through a[numberUsed -
1] have
13 //been rearranged so that a[0] <= a[1] <= ... <=
a[numberUsed - 1] .
14 void swapValues( int & v1, int & v2);
15 //Interchanges the values of v1 and v2 .
16 int indexOfSmallest( const int a[ ], int startIndex, int
numberUsed);
17 //Precondition: 0 <= startIndex < numberUsed. Reference
array elements
18 //have values. Returns the index i such that a[i] is the
smallest of the
19 //values a[startIndex], a[startIndex + 1],a[numberUsed - 1]
```

```
20 int main( )
21 {
22  cout << "This program sorts numbers from lowest to highest.\n";
23  int sampleArray[10], numberUsed;
24  fillArray(sampleArray, 10, numberUsed);
25  sort(sampleArray, numberUsed);
26  cout << "In sorted order the numbers are:\n";
27  for ( int index = 0; index < numberUsed; index++)
28      cout << sampleArray[index] << " ";
29  cout << endl;
30  return 0;
31 }
```

```
34 void sort( int a[], int numberUsed)
35 {
36  int indexOfNextSmallest;
37  for ( int index = 0; index < numberUsed - 1; index++)
38  { //Place the correct value in a[index] :
39      indexOfNextSmallest =
40      indexOfSmallest(a, index, numberUsed);
41      swapValues(a[index], a[indexOfNextSmallest]);
42      //a[0] <= a[1] <= ... <= a[index] are the smallest of the
43      //original array elements. The rest of the
        //elements are in the remaining positions .
44  }
45 }
```

```
46 void swapValues( int & v1, int & v2)
47 {
48  int temp;
49  temp = v1;
50  v1 = v2;
51  v2 = temp;
52 }
53
54 int indexOfSmallest( const int a[], int startIndex, int numberUsed)
55 {
56  int min = a[startIndex],
57  indexOfMin = startIndex;
58  for ( int index = startIndex + 1; index < numberUsed; index++)
59  if (a[index] < min)
60  {
61      min = a[index];
62      indexOfMin = index;
63  //min is the smallest of a[startIndex] through a[index]
64  }
65  return indexOfMin;
66 }
```

Multidimensional Arrays

- Arrays with more than one index
  - `char page[30][100];`
    - Two indexes: An "array of arrays"
    - Visualize as:
      `page[0][0], page[0][1], …, page[0][99]`
      `page[1][0], page[1][1], …, page[1][99]`
      …
      `page[29][0], page[29][1], …, page[29][99]`
- C++ allows any number of indexes
  - Typically no more than two

Multidimensional Array Parameters

- Similar to one-dimensional array
  - 1st dimension size not given
    - Provided as second parameter
  - 2nd dimension size IS given
- Example:

```
void DisplayPage(const char p[][100], int sizeDimension1)
{
     for (int index1=0; index1<sizeDimension1; index1++)
     {
            for (int index2=0; index2 < 100; index2++)
                   cout << p[index1][index2];
            cout << endl;
     }
}
```

Summary 1

- Array is collection of “same type” data
- Indexed variables of array used just like any other simple variables
- for-loop “natural” way to traverse arrays
- Programmer responsible for staying “in bounds” of array
- Array parameter is “new” kind
  - Similar to call-by-reference

Summary 2

- Array elements stored sequentially
  - “Contiguous” portion of memory
  - Only address of 1st element is passed to functions
- Partially-filled arrays → more tracking
- Constant array parameters
  - Prevent modification of array contents
- Multidimensional arrays
  - Create “array of arrays”